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Non-intrusive Time-lapse Video Monitoring of Shallow Aquatic Environments

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NON-INTRUSIVE TIME LAPSE VIDEO MONITORING OF SHALLOW AQUATIC ENVIRONMENTS

by

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ABSTRACT

Collins, N.C., S.G. Hinch, and K.A. Baia. 1991. Non-intrusive time-lapse video monitoring of shallow water aquatic environments. Can. Tech. Rep. Fish. Aquat. Sci., 1821. i-ix + 35 p.

Direct observation of organisms in the field is often necessary for an understanding of the intensity of various selective forces, and to evaluate how often in nature an organism finds itself in situations we create in the laboratory. Time-lapse video monitoring allows one to obtain detailed, direct observations over long periods, so that one can estimate the frequency of even relatively rare events. Using infrared illumination, relatively nonintrusive nighttime observations are now possible. Examples of some questions in fisheries ecology that can be quantitatively answered with this technology are: What species, numbers, and sizes of fish pass a particular point in a particular period? How do fishes respond to various types of passive fishing gear? How frequently do forage fishes or benthic invertebrates encounter predators? How important is predation on fish eggs and sedentary fish larvae? How important are various fish habitats as food sources for fish? What are the diel and seasonal patterns in the activity of fishes - exactly how active are they, how often do they feed, and what are their foraging tactics?

In this paper we identify the most important characteristics of the equipment necessary for underwater time-lapse monitoring, pointing out the characteristics of the currently available equipment that most limit performance. Our focus is on technical requirements, rather than on the capabilities of currently available equipment, so that the discussion should remain useful in

the face of substantial future developments in video technology. Some comparisons of cameras are provided to illustrate the range of capabilities available. Where possible, we have suggested how low-cost substitutes for commercially available equipment can be used. Finally, we describe the assembly of an infrared lighting system and present one test of its non-intrusiveness.

To facilitate use of this technology, we provide cost estimates for off-the-shelf and self-assembled systems and we list current sources of components in Canada and the USA. An observation system for a single site can be assembled for as little as $5900 Canadian; additional nearby sites sharing the same video recorder can be added for as little as $2600 each. The quality of the available equipment is increasing and costs are stable or decreasing.

RESUMÉ

Collins, N.C., S.G. Hinch, and K.A. Baia. 1991. Non-intrusive time-lapse video monitoring of shallow water aquatic environments. Can. Tech. Rep. Fish. Aquat. Sci., 1821. i-ix + 35 p.

Il est souvent nécessaire d'observer directement les organismes sur le terrain afin de comprendre l'intensité de différentes forces de sélection, et d'évaluer combien de fois, dans la nature, un organisme se trouve lui-même placé dans des conditions que nous créons en laboratoire. L'observation à l'aide d'un chrono-enregistreur vidéo permet à l'observateur d'effectuer des observations directes et détaillées couvrant de longues périodes; il peut ainsi estimer la fréquence de phénomènes même relativement rares. À l'aide d'un éclairage à l'infrarouge, il est maintenant possible d'effectuer des observations relativement non perturbatrices la nuit. Voici quelques questions dans le domaine de l'écologie des pêches auxquelles nous pouvons répondre de façon quantitative grâce à cette technologie : Quelles sont les espèces de poisson qui passent à un point donné à un moment donné, leur nombre et leur taille? Comment les poissons réagissent-ils aux différents engins de pêche passifs? Combien de fois des poissons fourrage ou des invertébrés benthiques sont exposés à des prédateurs? Quelle est l'importance de la prédation des oeufs de poisson et des larves de poisson sédentaires? Quelle est l'importance des différents habitats du poisson comme sources d'aliments pour les poissons? Quels sont les profils nycthéméral et saisonnier de l'activité des poissons - jusqu'à quel point exactement sont-ils actifs, combien de fois s'alimentent-ils, et quelles sont leurs tactiques pour trouver leur nourriture?

Dans le présent article, nous déterminons les caractéristiques les plus importantes du matériel nécessaire pour l'observation sous-marine par chronophotographie en précisant les caractéristiques de l'équipement disponible actuellement et qui limitent le plus la performance. Nous mettons l'accent sur les exigences techniques, plutôt que sur les possibilités de l'équipement actuellement disponible, de telle sorte que le débat devrait rester utile face aux progrès improtants futurs dans le domaine de la tehnologie vidéo. Nous comparons certaines caméras afin d'illustrer la gamme des possibilités offertes. Dans la mesure du possible, nous avons expliqué comment il est possible d'utiliser des appareils de substitution moins coûteux que les appareils actuellement disponibles sur le marché. Finalement, nous décrivons l'assemblage d'un système d'éclairage à l'infrarouge et nous présentons un essai de cette technique non perturbatrice.

Afin de faciliter l'utilisation de cette technologie, nous fournissons des estimations du coût pour des systèmes de série et à auto-assemblage, et nous dressons la liste des sources courantes des pièces au Canada et aux États-Unis. Un système d'observation pour un seul site peut être assemblé pour aussi peu que 5 900 $ canadiens; le même magnétoscope peut servir à l'observation d'autres sites avoisinants pour la modique somme de 2 600 $ chacun. La qualité de l'équipement disponible augmente et les coûts sont stables ou ils diminuent.

1.0 INTRODUCTION

Many questions about habitat utilization, food exploitation rates and species-species interactions in aquatic nearshore communities cannot be properly addressed without direct observation of animal activities in the field. Observations by divers have yielded much valuable information on invertebrates and fish (e.g. Chapman and Rice 1971, Hobson 1965, 1972, Emery 1973, Hobson and Chess 1976), especially during daytime in clear waters that allow observations from distances sufficient to avoid disturbing the subject organisms. The recent manufacture of very compact, battery powered, hand-held video equipment and the mass production of underwater housings for television and still cameras allow one to record and analyze in situ behavioral data in more detail than ever before.

However, direct observation or diver-operated video are not appropriate in a number of situations. In some environments diving may be too dangerous or dive times too limited to achieve one's objectives. In turbid waters observers may need to be too close to their subjects to avoid disturbing them. At night, diver-subject distances are reduced so that the possibility of diver disturbance of subjects is increased. Even the occasional use of lights at night may disrupt normal behaviour patterns (e.g. Chapman and Rice 1974). Finally, direct observation is usually not practical for the study of rare, short-lived events such as feeding attempts, behavioral interactions between individuals, or fish passes into or out of spawning streams. Adequate determination of the frequencies and consequences of such events requires nearly continuous, long-term records.

Disruptive effects of divers can be largely removed by mounting cameras on stands, and long-term visual monitoring has traditionally been accomplished using time-lapse

cinematography (Hersey 1967, George 1980). The expense of such movie equipment has limited the use of this approach (but see Butler (1989) for a remarkably inexpensive time-lapse system for monitoring conditions that change slowly or for documenting the frequency of events that last more than 20 s). However, in the last decade the surveillance industry has begun to produce small, low-voltage, low-light video cameras and time-lapse video recorders at prices that are now affordable. Relatively nonintrusive nighttime video observations are also possible. Ultra-low-light image-intensifying television cameras can make nighttime recordings in shallow water without the aid of artificial lighting, but such cameras are still too expensive (>$13,000 Canadian) for many applications. The capabilities of these cameras were reviewed by Holme (1984); we will not discuss them further. A more affordable alternative is to take advantage of the substantial infrared sensitivity of standard video cameras and use infrared lighting. With the existing technology, 24 hour time-lapse video monitoring of underwater environments is possible, and multiple-site monitoring is affordable.

In this article we describe the equipment necessary for continuous underwater video monitoring, discuss the advantages and disadvantages of various design features, and identify limitations on currently available equipment that we hope future models will supersede. Because the power requirements of time-lapse video recorders and sustained underwater lighting far exceed the capacity of batteries, we will discuss only systems in which cameras and lights are connected to surface video recorders and power supplies by cables. Some components can be inexpensively built by workshop personnel, which can substantially reduce costs where workshop labour costs are subsidized by one's home institution. We provide rough estimates of labour hours and materials costs required for such construction, as well as cost ranges for commercially available equivalents. All cost estimates are in Canadian dollars.

Because assembling a system will require a wide variety of components, we have also compiled appropriate manufacturer's addresses (Table 1).

2.0 CAMERAS AND ACCESSORIES

2.1 Cameras

Both tube-type and charge-coupled-device (CCD or chip) cameras are suitable for low-light applications. Because black-and-white cameras and monitors are both cheaper and have higher resolution than colour ones, we have used only the former. Holme (1984) comprehensively reviewed the low-light sensitivity of conventional tube and image intensified cameras. Almost all low-light cameras are available in low voltage models (one or more of 6 V DC, 12 V DC, or 24 V AC), which may be an important feature in aquatic operations to minimize electrical hazards.

Tube cameras like the Panasonic WV-1854 ($2300) are much more expensive, larger (40 cm long and 8-13 cm wide), heavier, and less durable than chip cameras. They exceed the performance of the latter only in the higher resolution achieved (700-800 horizontal lines, as compared with about 525 lines for the best low-light chip cameras, which cost about half as much). Because video recorders can presently preserve only 300-400 lines of horizontal resolution, the higher resolution of tube cameras is relevant only for applications where video images are digitized or interpreted in real time. We could not detect differences in resolution between recordings from a $2300, 700-line tube camera and those from an $830, 400 line chip camera.

Table 1. A partial listing of manufacturers and distributors of closed circuit television, lighting, and associated equipment. Where the manufacturer is based in Canada or the USA, only the headquarters address is given. For companies based outside North America, both Canadian and USA headquarters are listed. Local suppliers can be located in the Yellow Pages of the telephone directory, or by contacting the offices listed below. When a manufacturer's products do not span the complete range indicated in the category, its range is described in an annotation.

Closed Circuit Video Equipment

Burle Industries Inc., Security Products Division, 1000 New Holland Ave., Lancaster, PA 17601, 717-295-6000. Products marketed in Canada through SIS/RCA, 6 Baker Rd., Brampton, Ont. L6T 4E3, 416-793-8500.

Cohu Inc., 5755 Kearny Villa Rd., P.O. Box 85623, San Diego, CA 92138-5623, 619-277-6700. IR sensitive cameras, housings, underwater cabling, and control units only.

Hitachi Canada Inc., 6740 Campobello Rd., Mississauga, Ont. L5N 2L8, 416-821-4545. In USA contact Hitachi Sales Corporation of America, 1290 Wall St. W., Lyndhurst, NJ 07071, 201-935-5300.

Ikegami Electronics (USA), Inc. 37 Brook Ave., Maywood, NJ 07607, 201-368-9171, distributed in Canada by SSI 2000, 1192 Martin Grove Rd., Rexdale, Ont. MW9 5M9, 416-244-5700. Cameras and accessories, but no video recorders.

Javelin Electronics, 19831 Magellan Dr., Torrance, CA 90502-1188, 213-327-7440.

JVC Canada, 21 Finchdene Square, Scarborough, Ont. M1X 1A7, 416-293-1311. In USA contact JVC Co. of America, 41 Slater Dr., Elmwood Park, NJ 07407, 201-794-3900.

Matsushita Electric of Canada Ltd., 5770 Ambler Dr., Mississauga, Ont. L4W 2T3, 416-624-5010. Panasonic® equipment. In USA the headquarters is at 1 Panasonic Way, Seacus, NJ 07094, 201-348-9000.

Sony of Canada Ltd., 411 Gordon Baker Rd., Willowdale, Ont. M2H 2S9, 416-499-1414. In USA contact Sony Security Systems Co., 15 Essex Rd., Paramus, NJ 07652, 201-368-5018.

Underwater Equipment

Complete Systems

Fuhrman Diversified, Inc. 905 S. 8th St., La Porte, TX 77571, 713-470-8397. Outdoor and underwater television systems, mostly based on Sony 8mm equipment.

Camera Housings, Lights, Cables, Connectors, and Accessories

AMP of Canada, Ltd., 20 Esna Park Drive, Markham, Ont. L3R 1E1, 416-475-6222. Waterproof electrical connectors.

Amphibico Inc., 9563 Cote de Liesse, Dorval, Quebec H9P 1A3, 514-636-9910.

Birns, Inc., P.O. Box 909, Oxnard, CA 93932, 487-5393. Lights and their controllers, cables, and connectors.

Canadian General Electric, (see Yellow Pages for regional office; phone for USA operation for lamps is 216-266-4256). Lamps only.

Conxall Corp., 601 E. Wildwood St., Villa Park, IL 60801, 708-834-8540. Waterproof electrical connectors.

GTE Sylvania Canada Ltd., (see Yellow Pages for regional office). Lamps only.

Hypertech Inc., P.O. Box 10513, Pompano Beach, FL 33064, 305-782-4448.

Ikelite Underwater Systems, 50 W. 33rd St., P.O. Box 88100, Indianapolis, IN 46208, 317-923-4523.

Osprey Sub-Sea Inc., 753 Washington Ave., Escondido, CA 92025, 619-747-4223. British parent company, Osprey Electronics Ltd., represented in Canada by T. Thompson Ltd., with offices in Charlottetown, PEI (902-566-9202) and West Vancouver, BC (604-921-8300).

Peak Beam Systems, Inc., 14325 Frederick St. Suite 5, Moreno Valley, CA 92388, 714-653-2366. Portable, high intensity infrared lamps using xenon arc sources, not housed for underwater use.

Osram Canada Ltd., 6185 Tomken Rd., Mississauga, Ont. L5T 1X6, 416-670-1996. Lamps only.

Remote Ocean Systems, 5111 Santa Fe St, Suite L, San Diego, CA 92109, 619-483-3902. Lights, line voltage power sources, pan/tilt devices, and controllers.

Infrared Filters

Andover Corp., 4 Commercial Dr., Salem, NH 03079, 603-893-6888. Custom filters and coatings.

Eastman Kodak Co., Rochester, NY 14650, (gelatin filters only; request technical document B-3, Kodak Filters for Scientific and Technical Uses)

Kopp Glass, Inc., 2108 Palmer St., Pittsburgh, PA 15218, 412-271-0190.

Schott Glass Technologies Inc., 400 York Ave., Duryea, PA 18642, 717-457-7485.

Chip cameras are small (e.g. 12-17 cm long, 5 cm wide), light, consume less power, and are less subject to damage through vibration and tube-burn (where excessive light input damages the response characteristics of part of the video tube) than tube cameras. Their low-light sensitivity is nearly as great as that of tube cameras. Minimum scene illumination requirements are now about 0.12 lx (which is about equivalent to 0.01 lx at the chip), about the light level provided by a full moon. Most low-light chip cameras also have substantial infrared (wavelengths >700 nm) sensitivity, but the degree of infrared sensitivity varies substantially among cameras (Fig.1). Only sensitivity in the 720-820 nm range is important for infrared-illuminated work because some fish may be able to detect light near 700 nm, and because water transmits wavelengths >820 nm so poorly (Fig. 1). Chip cameras are usually sold with an infrared cut filter installed to eliminate infrared sensitivity, but the filter can be removed. Several manufacturers (Cohu, Ikegami, Javelin, Panasonic) produce especially IR sensitive cameras (Fig. 1) that offer varying degrees of increased IR sensitivity for nighttime observations; the tradeoff is that they cost about twice as much as less specialized low-light chip cameras. Some chip cameras come with a built in camera number generator that identifies the camera on the videotape. This option can be convenient when a switcher is being used to make recordings from a number of cameras cyclically on a single tape. Another option that may be useful in applications where light levels are adequate is an electronic shutter that will produce relatively unblurred still-frame images of rapidly moving objects, (with associated increases in light requirements). Without such a shutter, time lapse recorders will have an effective exposure time of 1/30 to 1/60 s, depending on the type of video recorder (see below).

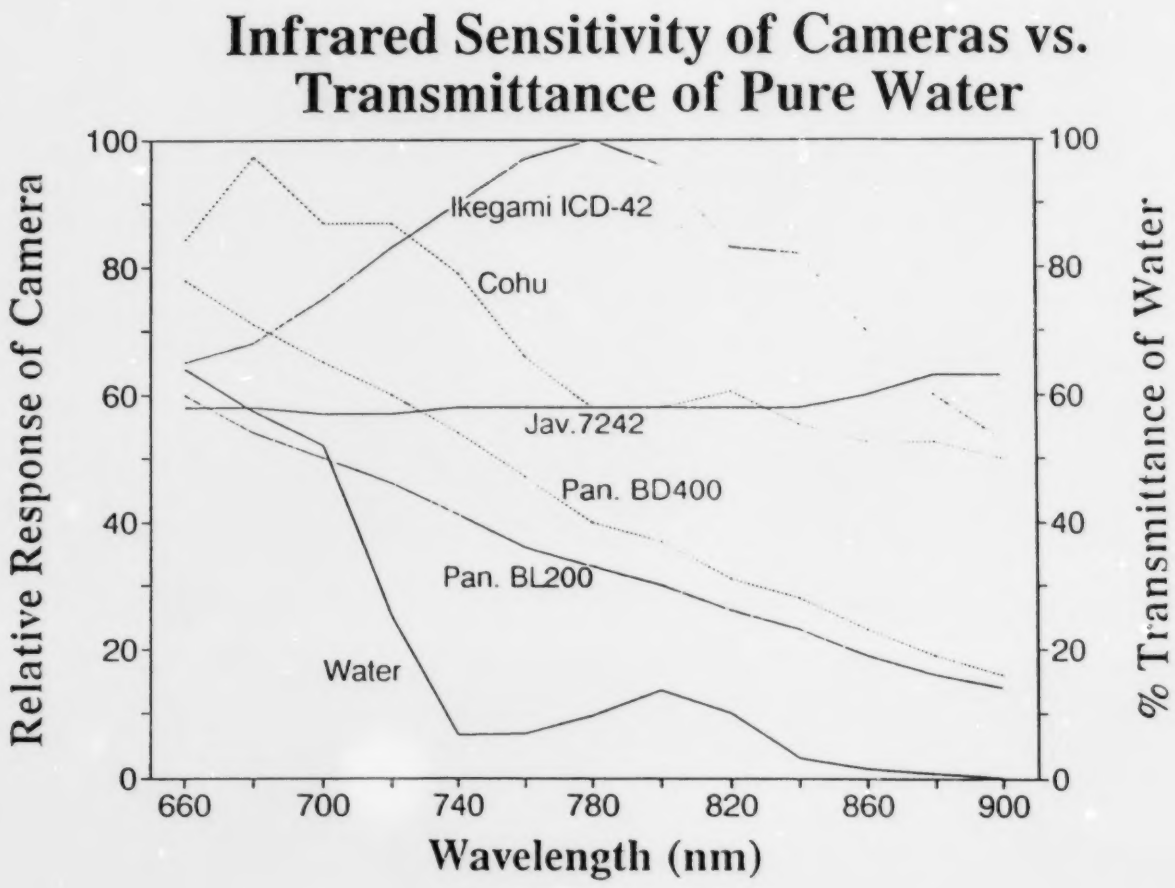

Figure 1. Transmittance of water per meter (Driscoll and Vaughan 1978 p. 15-29) and the sensitivity of a number of low-light CCD cameras to long wavelength visible light (<700 nm) and the lower end of the infrared range. "Relative response of camera" is the output of the chip as a percent of maximum output. All camera specifications are from manufacturers. These curves do not take into account differences in the overall light sensitivity of the chips, which range from 0.5 lx to 0.1 lx scene illumination, according to manufacturers' specifications. Cohu = Cohu Model 4710; Pan. BL200 and Pan. BD400 = Panasonic models WV-BL200 and WV-BD400; Jav.7242 = Javelin Model 7242.

2.2 Lenses and focusing

A wide range of lens options is available. Autoiris lenses are necessary for the large diurnal variations in light levels encountered. As mentioned above, relatively inexpensive ($150), plastic lenses are satisfactory for recorded observations of fish and invertebrates, as long as they have low minimum f numbers (e.g. 1.4) for good low-light performance. Better quality glass lenses ($350) may be important when real-time images are being analyzed without the loss in resolution inherent in videotape recording. Visibility underwater is limited by backscatter to a few meters (in freshwater) during the day, and at night to <1 m by the high rate of absorption of artificial infrared light by water. Under these circumstances, wide angle lenses are appropriate because they allow a large observation area close to the camera. They also provide improved depth of field. We utilize standard, Ikelite (Table 1) flat lens-ports on our camera housings, but the flat interface between the air and water reduces the effective angle of the lens (Holme 1984). Dome ports, which do not reduce viewing angle are available (Ikelite, Amphibico, Hypertech). They will also reduce optical distortion at the edges of the field of view. Six, 8, or 12.5 mm lenses for 1.3, 1.7, and 2.54 cm chip cameras, respectively, all produce a field roughly 58 X 45 degrees, which, through a flat port, translates to roughly 80 X 60 cm in size at 1 m from the camera.

Our cameras operate from fixed positions on stands, so that the problems of determining correct focus are minimized. A couple of procedures on shore help ensure that focus will be correct when the stand is placed underwater. If the camera is focused in air, one must focus at 3/4 of the desired distance because the optics in water are different than those in air (Holme 1984). Critical focusing is difficult on shore because the automatic iris of the lens is usually operating at a very high f-stop in daylight when the cameras are placed into position. The wide depth of field that this ensures makes it difficult to detect incorrect focus. A hood that covers both the stand and the camera, forcing the aperture of the lens to open up and reducing the depth of

field, can therefore be a useful focusing aid. Even if the camera is accurately focused on shore, the stand occasionally sinks into the sediments, or there may be a layer of macrophytes that effectively reduces the distance to the objects of interest, making further adjustments necessary. The ideal solution to such focusing problems would be a remote focus lens. Unfortunately for many researchers, this option is prohibitively expensive and logistically complicated, except in single camera operations. The remote focus feature is currently available only on zoom lenses, which are expensive; lens and controller systems cost $1300-3000, about 9-25X the cost of a plastic lens. In addition, remote focus systems require many additional conductors in the cable to the camera, which add both bulk and cost.

Our compromise with the focusing problem has been to add external focus capabilities to the camera housings so that the housing need not be opened to adjust the focus. Most commercial housings also include this capability (Ikelite, Amphibico, Hypertech, Osprey). External focusing can be installed at relatively low cost by piercing the housing with a shaft whose tip is threaded so that it engages gear teeth glued to the focus ring of the camera lens. (Note that some Sony miniature cameras are focused via a screw at the back of the camera, and may require a different external focusing arrangement). The hole for the shaft is waterproofed with O-rings and an external knob on the shaft allows it to be turned to move the focus ring inside. A flexible rod from the focusing knob to the surface allows the camera to be focused from a boat above.

2.3 Cables to the cameras

In our experience, 160 m of cable between the camera and video recorder has allowed more than adequate flexibility in camera placement. A high quality shielded coaxial cable bundled with two AWG 22 conductors and a ground (RG-59/U, Belden cable 9265, $650 for 160 m reel)

is durable and provides a good video signal over these cable lengths. Camera specification sheets provided by manufacturers indicate that RG-59/U cable would allow cable runs of 110-250 m, depending on the camera. The lower end of this range may be restrictive to some users, so it is important to establish this aspect of camera capability before buying. Voltage to our cameras drops substantially between the transformer on shore and the cameras. We have found that using the ground wires as duplicate conductors in the circuit to the cameras reduces this voltage drop, allowing the cameras to run closer to nominal voltage.

Some manufacturers (e.g. Panasonic, Sony) offer a simplified cabling system in which power to the camera, the video signal, and a synchronization signal are multiplexed together along a single coaxial link. For applications where the synchronization signal is important, such as where a switcher is interleaving signals from multiple cameras for recording on a single tape (see Recording from Multiple Sites, below), these multiplexed systems will reduce the bulk and cost of cabling by more than 50%, which can translate into savings of $200-$300 per camera for 150 m cables.

2.4 Camera housings

A variety of custom housings made for cameras alone (instead of camera-recorder combinations) are available commercially (Sony, Cohu, Amphibico, Osprey, Hypertech, Ikelite), usually for about $1500. Ikelite also manufactures a variety of basic housings designed to be modified for particular needs, for about $200. Sony manufactures an especially inexpensive ($200) housing for its miniature cameras and sells waterproof cable to connect it to the surface. However, the cable comes in 20 m sections only ($180), and even if longer runs were available, the user would have to incorporate a waterproofed video amplifier every 40-50 m along the cable

to maintain signal quality. For researchers monitoring locations very near their surface base, however, the Sony system may be the simplest and cheapest solution.

For those building their own housings, plexiglass was for a long time the traditional material for custom housings. Large housings we used for tube cameras frequently developed leaks, presumably because shocks, vibrations, and expansion or contraction from temperature/moisture changes opened up glued and bolted joints. Even minor leaks cause problems, given that the internal pressure in the housing is lower than that of the surrounding water when the housing is submerged. The high humidity in slowly leaking housings can fog the lens or port, and it sometimes causes wobbling and distortion of the video image. Minor leak problems can be eliminated by introducing a pneumatic tire valve into the back of housings so that they can be positively pressurized with a bicycle pump. We also add an envelope of desiccant to the housing to help eliminate water condensation on the lens or port.

We have found 1 cm thick PVC housings to be more durable than plexiglass ones in our application. Sheet aluminum also works. With either of these materials, joints can be welded, instead of glued and bolted, substantially increasing the strength of the join. Our housings are rectangular boxes with a standard Ikelite port set into the front, and with a removable back secured by spring latches and sealed with an O-ring. The pressurization valve penetrates the removable back of each housing. Power and video cables also penetrate the back and the cable entry points are kept watertight using standard brass compression fittings with nylon bushings. The back of each housing is permanently connected to the end of the cable, and is stored with the cable reel. However, a variety of waterproof connectors (Amp, Birns, Remote Ocean Systems, Conxall) can be incorporated into the housing back, so that the housing, once charged with desiccant and pressurized, need never be opened. Such a system would be especially

useful where equipment must be set up in the rain. Manufactured housings often already incorporate such refinements.

The only other attachments to our housings are two aluminum sleeves to hold the PVC pipe (wall thickness Schedule 80) that supports the lights, and to allow the housing to be attached to the camera stand (which is made of 2 cm dia galvanized pipe; the entire stand costs approximately $30). The camera attaches through its tripod bolt hole to an aluminum plate that slides into a groove at the bottom of the housing. One PVC housing can be made for $120 materials and approximately 30 hours labour.

3.0 ILLUMINATION AND POWER SUPPLY

Although the chip cameras we use are sensitive to low light levels, artificial illumination is necessary at night. Laboratory evidence suggests that visual pigments in the rods of fish eyes do not absorb in the infrared (Bridges 1964, Lythgoe 1988). Cone pigments of some species may be infrared sensitive (Lythgoe 1988), but only at light intensities about 3 orders of magnitude above that for rods. Therefore, low intensity infrared is probably invisible to fish, with this probability increasing with wavelength. Insect vision is concentrated even farther toward the blue than that of fish (although only aerial forms have been studied: White 1985). Therefore infrared light (wavelengths >700 nm) may provide the appropriate illumination for non-intrusive nighttime observations. Since 45-100% of infrared light is absorbed within one meter of water over various parts of the infrared range (Fig. 1), even organisms that could detect and respond to infrared would not be able to detect artificial infrared sources more than a 1-2 meters away - additional insurance that this lighting will not bias measurements of activities of organisms in the field.

The use of infrared illumination involves three practical considerations: (1) choice of an appropriate light source and reflector (2) elimination of visible light from the beam, and (3) provision of adequate power to the lights. These problems will be discussed in turn below.

3.1 Illumination source

The best light source is the one that will provide the highest intensity in the infrared per watt of power consumed, will have a beam width of at least 50 degrees (for 2-lights per wide angle camera), will stand up to uneven heating/cooling associated with operation while partially wet, and will have a long filament life. The most appropriate spectral output is provided by tungsten filament, halogen filled bulbs, which provide most of their energy in the infrared range (Anonymous 1989), and have much higher light output per watt than normal tungsten filament, vacuum bulbs, which operate at lower filament temperatures (<2800 K versus up to 3400 K; Kelvin temperature of the filament is directly related to light output per watt (Anonymous 1988)). For sustained observations, and especially when waterproofing and light-proofing bulb housings involves time-consuming sealing processes, bulbs with long rated service life (e.g. 1000-2000 hours) are necessary. Seventy-five watts of power to each of two wide angle 3000 K halogen bulbs mounted next to the camera will, when visible light is removed by a filter, illuminate a 40 x 60 cm area 50 cm from the camera with the camera lens aperture at maximum (f 1.4). Higher wattage bulbs will be more satisfactory when the necessary power is available and cabling is suitable to deliver enough power to the lights (see below). Some suitable bulbs come with built-in reflectors (e.g. Osram 41800 series, Sylvania Capsylite series), and socket-reflector combinations are also available commercially from manufacturers of underwater lights (Table 1). The widest angle floodlights (50-60 degrees) are necessary for compatibility with wide angle camera lenses. Dichroic reflectors should be avoided because they are designed to let infrared wavelengths pass through, so that the reflected beam is infrared poor.

For close-up observations of aquatic invertebrates or other situations where small areas are being illuminated and only short light paths (<30 cm) are required, the use of infrared LED's is possible. LED's come with the lens end hermetically sealed and ready to be submerged and they are available in narrow and wide angle models. However, most of the currently available LED's produce their peak light between 875-950 nm, with bandwidths about 100 nm between wavelengths where radiant power output is 50% of the peak. Because the transmittance rate of water is so low at wavelengths longer than 840 nm (Fig. 1) only the lower end of the shorter wavelength tail of the spectral output of the LED's will be at all effective in lighting. If LED's become available that deliver peak radiant power output at 800 nm, they will be much better sources of underwater lighting because water exhibits a minor peak in transmittance at that wavelength (Fig. 1). The low power of the currently available LED's (up to 12 mW radiant power output) means multi-element arrays are necessary. In our experience, arrays of 40-80 12 mW LED's (TRW model OP233W at $2.11 each) are necessary to provide illumination for a 55 degree viewing field 20 cm from the camera (when the LED's are mounted next to the camera, producing a light path length of roughly 40 cm). LED output can be increased by driving them with a pulsed input voltage, but doing so complicates the power supply and the problems of delivering this power down long cables underwater. Until more powerful LED's become available, we feel the inconvenience of having to wire all of the units in the array and to waterproof the connections, makes LED illumination a clumsy option that is at least as expensive as ordinary lights and a filter.

3.2 Infrared filters

We have experimented with gelatin and glass filters. The Kodak Safelight Filter #11 ($50), a gelatin matrix bonded to a 14 cm dia piece of glass, transmits light above 780 nm, peaking at

900 nm (Fig. 2). Because its gelatin coating is water sensitive, it must be waterproofed. We do this by enclosing it between circular pieces of plexiglass and sealing the edges with silicone sealant. The underwater life of this filter is 4-5 weeks because it deteriorates and seems to become more opaque with use. Because it does not transmit in the 700-780 nm wavelength range where water is most transparent to infrared, usable light output is low. Under field conditions using pairs of 75 W quartz-halogen bulbs for illumination, the Kodak #11 filter is useful at recording images of subjects that are not more than 0.3 m from the camera. The main advantage of this filter is that it does not appear to transmit any light visible to us.

Glass filters do not have to be waterproofed and will last indefinitely underwater provided they are given room in their housing to expand as the lamp heats them up, and provided they do not heat too unevenly (they have rather high coefficients of thermal expansion that can produce stress from uneven heating). The Kopp filter 7-69 (about $170 when dia >8 cm, considerably less when smaller) transmits light above 690 nm, peaking around 780 nm, and the Schott RG780 blocks more visible light and peaks around 820 nm (Fig. 2). Both of these glass filters take better advantage than the Kodak filter of the higher light transmission rates of water in the 700-780 nm range, but although the Kopp's specifications indicate the 3.5mm standard thickness transmits less than 0.001% of light below 680 nm, the light from 75 W bulbs is intense enough (maximum 68000 lx at the filter face) so that the source is clearly visible to us underwater in the dark, even through extra thick 4.5mm filters. (The increased thickness should reduce transmittance of visible light by 20-40 times while reducing only slightly the transmission of infrared in the 700-760 nm range where water is most transparent.) Using this thicker filter the maximum intensity of visible light in the beam was <0.5 lx at underwater distances >0.2 m away (using a LiCor quantum sensor sensitive to the 400-700 nm range). The Kodak #11 filtered source is invisible to our eyes

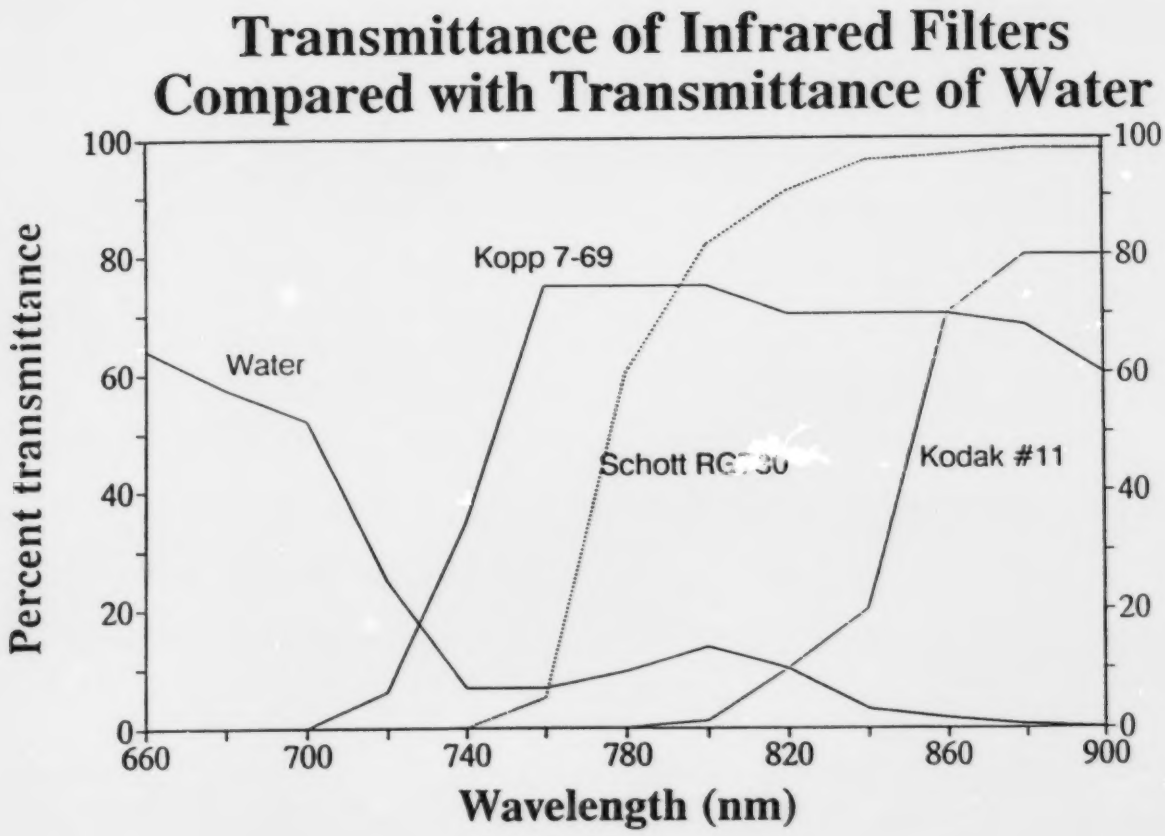

Figure 2. Transmittance of three commercially available infrared filters in comparison to that of pure water. Values for water are per m (Driscoll and Vaughan 1978 p. 15-29). Values for infrared-transmitting Schott RG780 and Kopp 7-69 filters (Anonymous 1987,1986) are for 3 mm thick versions. "Kodak" refers to the Kodak #11 safelight filter (Anonymous 1981).

at 20 cm underwater. We have not actually used the Schott RG780 in the field, but its specifications indicate it may be a good compromise between the Kodak and Kopp filters, transmitting less visible and more infrared in the critical wavelength range.

In a field test to determine whether lights filtered with 4.5mm Kopp 7-69 filters were attracting or repelling fish or invertebrates at night around the camera site, we switched off the lights for 15 min, then compared fish and invertebrate traffic in the water column during two consecutive 7 min periods after the lights were turned on. In mesotrophic Lake Opinicon, Ontario, at a site where fish traffic included mostly Lepomis gibbosus, and L. macrochirus, we found no evidence of any accumulation or depletion of organisms between the first and second 7 min periods (Wilcoxon test for matched pairs, $n=12$, $p >> 0.05$.

The Kopp glass filters, when lights are mounted next to the camera, allow camera-subject distances to be increased from 0.3 m (with the Kodak filter), up to .8 m in clear water, when an ordinary chip camera is used. Utilizing the more expensive cameras designed to be more infrared sensitive should allow one to light subjects 1.0 m from the camera in very clear water.

To summarize, the Kodak #11 safelight filter transmits a beam that is almost certainly invisible to the fish, and we have used it successfully in the field. However, it provides less light than is desirable for many applications. Both the glass filters provide much more light for the cameras, but the Kopp 7-69 also transmits some visible light. To date there is no evidence that the low intensities produced affect fish or invertebrate traffic; the lights appear to be nonintrusive. Nevertheless, until more powerful tests of intrusiveness are carried out, it will be prudent to use filters such as the Schott RG780, that more effectively block visible light, and to maximize camera-subject distances by obtaining the most infrared-sensitive cameras available. The

nighttime suitability of various filter-camera combinations can be compared by combining the transmittance spectra of various filters with the spectral responses of various cameras (Fig. 3). This comparison, based completely on manufacturers' specifications, indicates that the Schott RG780 filter should limit total infrared light input very little, in comparison with the Kopp 7-69, while reducing substantially the amount of visible light transmitted (Fig. 2).

3.3 Light housings and filter holders

A variety of commercially produced underwater lights and housings are available (Amphibico, Osprey, Birns, Remote Ocean Systems, Hypertech) for connection with surface power sources. Most could be easily modified to accept an infrared filter (see below). Commercially purchased infrared lighting for a single camera, using a single wide-angle light source to minimize cable costs, would cost $700-$1500 for a light, plus about $6/m for cable, totalling $1600-2400 for a 150 m cable run. Such a system will be durable and electrically very safe, but for most researchers, who will require more than one setup for their work, this price is too high. Fortunately, cruder, but effective and safe alternatives can be assembled for only $500, including cable costs.

Lamp-reflector combinations (e.g. Osram 41800 series) can be purchased from manufacturers for $15-30 and waterproofed, or a pair of pre-waterproofed lights can be purchased for $250-$500 (Amphibico, Remote Ocean Systems). A circular brass hood is then constructed around the front of the reflector/housing to support the filter and to conduct all the light from the lamps through it. In our current design, cooling water is allowed to circulate between the filter and the bulb or lamp face by convection, via brass venting tubes that are inserted into the brass hood and bent to prevent light leakage. The rear of the lamp extends behind the hood and is exposed to the water. Black electrical tape wrapped around the housing and back of the lamp can

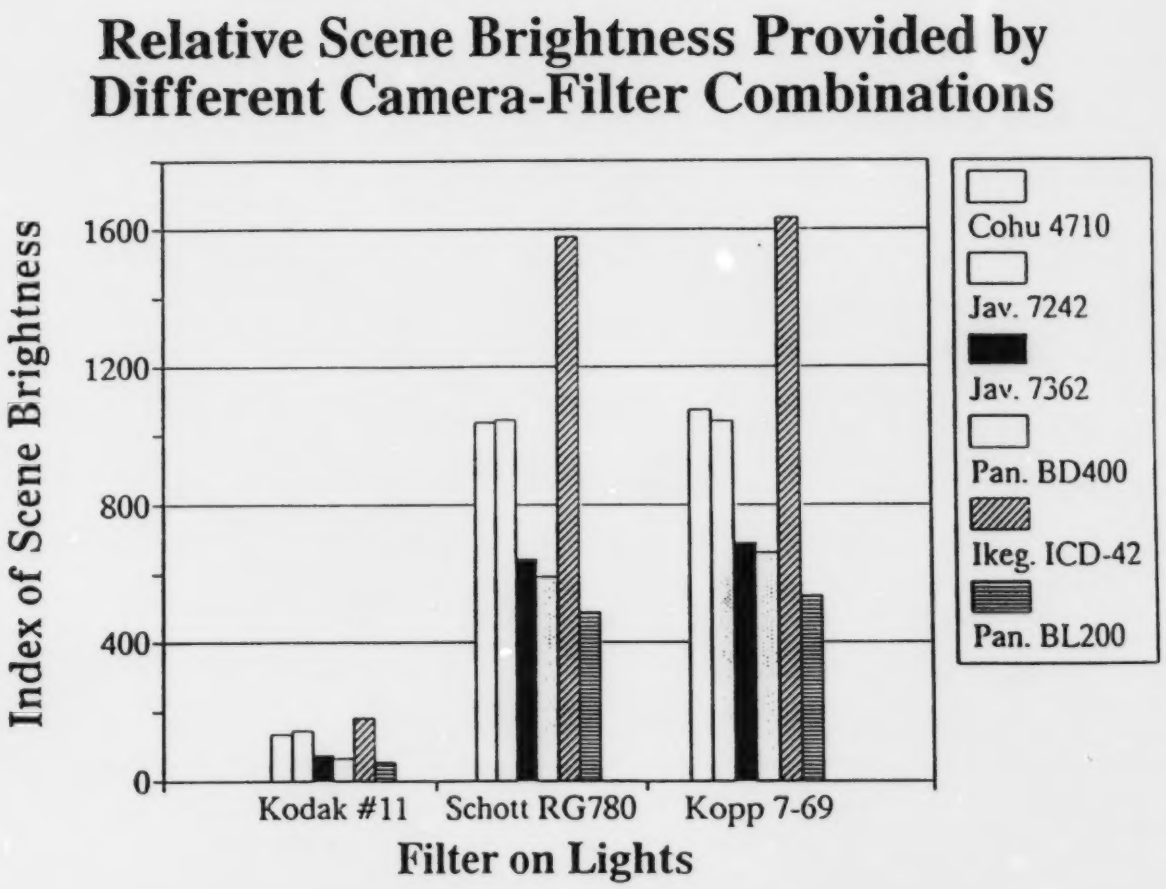

Figure 3. Calculated light response index of six low-light CCD cameras to light from a 3000 K quartz-halogen bulb filtered through a variety of filter types in an underwater environment. "Response of camera" equals the product of the following four variables, summed over the wavelength range from 700-1100 nm: the spectral emittance of the lamp in $W.s.m^{-2}$ (calculated using Planck's formula (Sears and Zemansky 1964 p. 381)), the fraction transmitted by the filter (Fig. 2), the fraction transmitted by 1 m of water (Driscoll and Vaughan 1978 p. 15-29), and the relative response of the camera (Fig. 1). Values on the abscissa should be a measure of the relative brightness of a scene photographed with any camera filter combination.

eliminate leaks of visible light. Dark coloured silicone sealant or Peel Coat, a quick-setting thermoplastic coating (Type B-100, available in black from Evans Manufacturing, Inc., Troy, Michigan USA) can be used to waterproof the connections between the lamp and power cables, and the lamp and its socket. Waterproof connectors (Amp, Conxall, Birns) can be mounted on the power cable and short lead-wires from the lights. Such a housing/filter holder can be made for $20 in materials and 5 h labour.

Allowing water to circulate between the reflector or lamp face and the filter keeps temperatures low and prevents burning of gelatin filters and cracking of glass ones because of uneven heating. However, the cooling water eventually fouls the reflector and filter surfaces reducing the effectiveness of the lights, requiring disassembly of the filter hood and cleaning of the surfaces after every few weeks of use. Another disadvantage of the circulation system is that the high temperatures of small tungsten-halogen bulbs boil the cooling water on their surface, producing popping sounds that are audible underwater. Completely waterproof lamp housings using glass filters that will not burn, and constructed of metal to facilitate cooling are clearly to be recommended over the open systems we have used in the past.

3.4 Powering the lights

Infrared lighting for one camera demands 150-200 W of power be delivered to the light(s), which may require 320 W to the circuit when line losses are considered. Today's batteries could not meet these demands for more than a few hours, so surface power is a necessity.

There are a number of alternative approaches to the problem of delivering adequate power to the lights down long cable runs, while protecting operator safety. One approach is to use standard 120 V power lines, 120 V lamps, and to install ground fault protectors for safety.

Operation at normal line voltage means that current requirements for the lights are low, and there is very little loss of voltage down long cable runs. The ground fault protector ($27) is a device that detects significant current leakage to ground and breaks the circuit quickly enough to prevent electrocution of a person who happened to be part of the short to ground. (It does not protect operators who simultaneously contact the positive and negative terminals). The 120 V ground fault protected setup requires use of a more expensive 3-conductor instead of a 2-conductor cable (a ground wire is necessary to provide the reference for the ground fault protector), but it does not require any transformers in the line to convert 120 V to lower lamp voltages, a saving that offsets the extra cabling costs. The high voltage differentials between the conductors mean that any minor failures in waterproofing of cable or connections will result in high current leakage rates that will disable the system by triggering the ground fault protector. The 120 V option is therefore probably most appropriate when commercially available, professionally constructed light housings, cable, and connectors are being used. However, these systems will be relatively expensive when compared with a self-assembled low voltage system like that described below.

In a low voltage system a transformer on shore converts line voltage to a lower level, and high amperages are necessary to deliver the necessary power to the lights. For example, over 8.33 amps of current are necessary to deliver 200 watts of power (for lighting one camera site) at 24 volts. At these high amperages, cable resistance becomes very important and voltage drop along the cable becomes a problem that must be compensated for by increasing the voltage input to the circuit. We calculated costs for use of 12 V or 24 V lamps, wired either in series or in parallel, with the safety restriction that no more than 40 V input be necessary (Table 2). The most economical configuration is to use two 12 volt lights wired in series to a 38 V, 320 W transformer to provide lighting for a single camera. For 150 m cable runs, voltage drop becomes

Table 2. "Assemble it yourself" costs of cabling and related equipment for delivering power to two 100 watt lamps (12 and 24 volt options) or one 200 watt lamp (the cheapest 120 volt option) at a camera site. Only the most economical configurations are listed. For 12 and 24 volt lamps, only configurations requiring <40 volts of input were considered, for safety reasons. This criterion eliminated the series wiring option for 24 volt lamps and constrained the cable thickness for 12 volt lamps. All costs are in Canadian dollars.

Line Length	Light Voltage	Light(s) Wired in:	Cable Cost	Other Parts[a]	Input Volts	Total Cost
150 m	12	Series	291[b]	101	38	392
	24	Parallel	374[c]	101	35	475
	120	1 lamp[f]	300[d]	27	118	327[•]
100 m	12	Series	125[c]	101	39	226
	24	Parallel	176[d]	101	35	277
	120	1 lamp[f]	200[d]	27	117	227[•]

[a] High load transformer or ground fault protector

[b] AWG 12 cable necessary to reduce voltage drop in lines

[c] AWG 14 cable necessary to reduce voltage drop in lines

[d] AWG 16 cable

[•] This is an "assemble it yourself" cost. However, self assembly may not be wise for 120 volt supplies (see text).

[f] Commercial cost of this option would be $1600-$2400.

more of a problem, and AWG 12 cable will be necessary; for many applications 100 m cables will be sufficiently long, and cheaper AWG 14 cable can be used. As well as being the least expensive, the 12 V series-wired option is also the most attractive logistically, because it requires only one bulky cable per camera instead of the two cables required for parallel wiring arrangements.

4.0 VIDEO RECORDERS

Time lapse recorders, used in the surveillance industry, are currently available in three recording formats: VHS, S-VHS, and 8 mm. S-VHS format offers an improvement in resolution over VHS - 400 horizontal lines in both colour and black-and white, compared to 240 and 350 lines, respectively for the best VHS machines. However, achievement of the higher resolution in colour requires very precisely constructed pre-manufactured cables between all components of the video system, and the longest of these commercially available currently is only a few meters long. For 400 line resolution in black and white, no special cables are required, but special S-VHS tapes are necessary, and these currently cost about 3X as much as high quality VHS or 8 mm tapes. For a single small monitoring project that requires 20 tapes, this price difference would be $280. S-VHS recorders will accept normal VHS tapes, but when they do so they automatically use normal VHS electronics and achieve only 300 lines of resolution in black and white. The better models of recorders in VHS S-VHS, and 8 mm formats claim roughly comparable horizontal resolution in black and white (VHS 350 lines, S-VHS 400 lines, 8 mm 380 lines), and they exhibit a range in video signal/noise of 40-48 dB (a 3 dB change represents roughly a doubling of the ratio). Prices currently range from $2600-$7000 and suitable units are manufactured by Panasonic, Javelin, Hitachi, JVC, RCA/Burle, and Sony, among others (Table 1).

Time lapse videocassette recorders (VCR's) in either format can be classified as either "field" or "frame" recorders. Frame recorders record images called fields 60 times per s, and on playback interlace the alternate horizontal lines of pairs of adjacent fields to form 30 composite "frames" per s, each with an effective exposure time of 1/30 s. Field recorders record in the same way as frame recorders, but instead of interlacing horizontal lines of adjacent fields on playback each field is played separately. Field recorders therefore have an effective exposure time of 1/60 s. For applications where objects of interest move quickly and have to be carefully identified or measured, the shorter exposure time of field recorders reduces the degree of blurring of single images of moving objects on the monitor. Sony, Panasonic, and JVC now make recorders that can operate in either frame or field mode.

All time-lapse recorders allow the operator to vary the interval between records in time-lapse mode, usually over a range from a fraction of a second to several seconds. The changing interval extends the amount of time recordable on a single tape from the nominal 2 hours to up to 3 weeks. In practice the user needs to ensure that the inter-record interval required to see the events of interest can be combined with a convenient interval between tape changes (e.g. for many applications 12 hour intervals will be very inconvenient, while 24 hour intervals would be fine), and with a comfortable degree of time acceleration during playback. If the interval between recorded images is too long, the tape record will underestimate the frequency of shorter-lived events, as is illustrated by the very different estimates of rates of fish passage over a lake bottom obtained by Butler (1989), who recorded one super-8 film image every 20 s, and Collins (1989), who used a time lapse video system with a recording interval of 0.2 seconds. Butler's much lower estimates result from the fact that fish usually spend only a second or two in the field of view of the camera, so that most such events are missed if the interval between images is longer than 1-2 s. Shorter-lived events like feeding attempts require an even shorter sampling interval

to be sure they are not missed. We feel a sampling interval of 0.2 seconds ensures virtually complete coverage of ecologically important events, although even this interval may be too short for good estimates of reactive distance to prey in the field. Inter-record interval also determines the degree to which time will be accelerated during playback of the tapes at normal tape speed. The time acceleration factor is the ratio of the number of hours required to fill a tape, divided by the number of hours required to play it back at normal tape speed (30 frames or 60 fields/s, requiring 2 h for a T-120 VHS tape). Playback at normal tape speed provides a continuous, non-flickering image that is easier to watch than playback at slower speeds. We find it most comfortable to review tapes at 12 times normal speed, stopping when events occur to review things more carefully at slower speed. Substantially lower time acceleration factors unnecessarily increase tape transcription time, and 24 times normal speed is too fast for comfortable review of even moderate event frequencies.

Using the above criteria, VHS or S-VHS field recorders currently appear to provide the best operating characteristics for sustained, yet near-continuous monitoring of fish and invertebrate activities in shallow aquatic environments. At a convenient tape replacement interval of 24 h they record an image every 0.2 s that can be played back smoothly with a time acceleration factor of 12. For VHS or S-VHS frame recorders time resolution would drop to 0.4 s, but other characteristics would be the same. The most appropriate 8 mm machine (Sony EVT-801), at a 24 h tape change interval (for a P6-90 tape) would record images much less frequently (0.5 s intervals) and would play back at 16 times normal speed. All of the above factors could change as new recorders and new tape lengths become available, so prospective buyers should check current specifications. It is also important for buyers to have VCR's demonstrated, because playback quality differs substantially both among machines and among combinations of recording speed and playback speed within a machine.

Additional important features of recorders include the characteristics of the time-date generator and the availability of remote controllers. In environments where significant events occur more frequently than once every 10 min, remote controls considerably reduce the fatigue associated with reversing the tape, slowing down the speed, and reviewing the event. Unfortunately, remote controllers are not available for some recorders. Recorders also differ significantly in the amount of information in the built-in time-date stamp, and in its size. We have found it important to have the recording speed specified on the tape, and would prefer the stamp to be as small and unobtrusive as possible. The ability to control the colour and brightness of the time-date stamp is also useful, especially when making nighttime recordings. We have found that light-coloured lettering is necessary to ensure its visibility against dark nighttime backgrounds, but bright white lettering reduces the range of grey tones seen on the monitor in the background image of interest. The brightness of the lettering can be adjusted on a number of machines. A number of machines now project time and date as a black outline around white letters, a near perfect combination as long as the brightness of the white can be adjusted. In some machines the time-date stamp appears on a rectangular block that masks completely the video image behind it. Less information is lost if only numerals of the time-date record are written over the camera image.

Most time-lapse recorders are designed to respond to external "alarm" signals by switching from the time lapse recording rate set by the operator to a rate of 30 frames or 60 fields per second for a predetermined number of seconds, then switching back to time lapse mode. This capability allows the user to record at infrequent intervals most of the time and to record more detailed information when significant events produce alarm signals. Alarm signals can be generated by video motion detectors ($350-$600) or by mechanical or optical switches set in the field of view. For field monitoring of fish we have found motion detectors and alarm mode

ineffective for two reasons. First, the frequency of motion detector alarms generated by moving shadows of surface waves or passing fish is so high that alarm mode recording is almost continuous. Constructing switches that are tripped by specific, rare events will be more effective than the use of motion detectors. The second problem of alarm recording is that when an alarm occurs, recording is interrupted for perhaps .5-1 s while the video recorder changes recording speeds, and this break in the record often includes the most significant part of an alarm event. Constructing switches that are tripped a second or so before a particular event, to allow complete records of the entire event, may be difficult in many circumstances.

5.0 MONITORS

A video monitor ($300-$600) is a necessity in the field to focus the cameras, aim the cameras and lights, check for minor leaks in the camera housings, or review tapes. A wide range of sizes is available, and smaller monitors are certainly more convenient in the field; however, critical camera focus may be difficult to ascertain with the smallest ones, and users should conduct focusing tests with screens smaller than 15 cm diagonal before purchase.

One of the most important monitor features is underscan capability, wherein the image is shrunk to allow viewing of the edges of the recorded image that are normally projected beyond the edges of the screen. Reviewing tapes with underscan in effect increases the effective area monitored, which will usually improve the precision of estimates of event frequency. Many monitors lack this capability. Most monitors achieve greater than 600 lines of horizontal resolution, which is far better than most cameras or the best VCR's. Therefore, the quality of video playback is not limited by the monitor.

6.0 RECORDING FROM MULTIPLE SITES

For many kinds of events, such as passes by fish through the field of view, good estimates of rates for a particular time of day can be obtained from only 10-30 min of observation. This means that records of diel patterns of activity can be obtained from several sites at a time by cyclically recording for a few minutes from an array of cameras. Our workshop built a video switcher that alternately routes the input of two or three cameras to a single video recorder at programmable intervals, effectively doubling or tripling the sample size of sites that can be examined, without requiring investment in another video recorder, the most expensive part of the system. Our switcher can be assembled with 10 h labour and $160 in materials, and it allows switching intervals of 0.5-30 min. (The circuit diagram or circuit board design and a parts list is available through the authors.) Commercially produced sequential switchers are not appropriate because they do not allow switching intervals longer than about 90 s.

Reductions in the cost of equipment per site that the switcher allows are important because we have found that there is high spatial variation and even higher among-day, within-site variation in fish traffic and benthic exploitation rates, so that single-site and single-day data are not representative (Collins 1989, Hinch and Collins submitted). Additional equipment to use a multiple camera approach (i.e. the switcher, one additional camera with housing, 100 m of cabling, and lights) costs approximately $2600, which is less than half the cost of a one camera stand-alone system because the video recorder and monitor are not required.

Another important contribution of the switcher is that it allows near-simultaneous monitoring of control vs. experimental sites, or of pairs or triplets of preexisting sites that contrast in specific ways. This allows us to factor out of paired comparisons the temporal variance in activity and thereby greatly increases the power of the sampling design.

The switching system above allows multiple site monitoring by giving up continuous monitoring of any particular site. Continuous monitoring of multiple sites is possible using commercially produced video signal splitters/multiplexers, some of which are called "quad units"). The simplest units take inputs from four cameras and allocate them to the four quadrants of a single output image that can be displayed and recorded. In real time an operator can expand any camera input to full screen size for examination in more detail, and quad units may respond to alarms (e.g. from motion detectors) by expanding the corresponding camera input to full screen, or by freezing the image present when the alarm occurs. Once the output of the quad unit is recorded, however, expansion of particular screen areas is no longer possible for some multiplexers. For other, more expensive units, information from all sites is simultaneously encoded on the tape and full screen viewing can be recovered from the recording. A synchronization signal to coordinate inputs from all cameras may be required to achieve this for some brands of multiplexer. For standard cameras an additional coaxial cable to each camera would be required to carry this signal. As mentioned earlier, some manufacturers (Panasonic, Sony) produce equipment that can carry the synchronization and video signals on a single cable. Another (Burle) produces a high-end multiplexer that does not require a synchronizing signal. Where one cannot afford to miss observing any event during the study period, quad units or multiplexers can be very valuable, but the units currently available have one substantial restriction: the interval between frames recorded from any specific camera increases with the number of cameras. Therefore, these units will not be effective for situations requiring recordings at 0.2 s intervals; with three cameras being recorded the recording interval for a particular camera will range from 0.6 s to more than 1 s, depending on the multiplexer brand. Potential users should require demonstrations of these units to be certain they meet the specific requirements of the project. Prices range from $2000-$7000; local distributors of closed-circuit television and security systems are the best sources of information about the models currently available.

7.0 POWER GENERATOR

About of 650 watts power is needed to run two cameras with pairs of 12 volt 100 W lights wired in series, connected through a switcher to a single VCR. More than 70% of this is required for the lights. Some field situations will require gasoline or diesel electrical generators to produce the AC current for the video system. In our experience, a 1.4 kW generator (approximate cost $1000) is portable and durable enough for long-term (i.e. over several weeks) continuous recordings using two complete camera systems. Any problems with generator "noise" on video images have been only minor. Depending on the power demand most small generators will last 4 to 6 h on one tank of fuel, therefore long-term, unattended recordings are only possible with enlarged generator fuel tanks or fuel provided through a continuous feed, external source. Most generators produce AC current at a frequency of 50-60 Hz. The frequency changes as the power demand on the generator changes, therefore lights turning on/off throughout the day will cause variation in the AC frequency. Some AC timers that are used to control the times at which the lights go on and off are sensitive to changes in AC frequency and may run fast or slow by an hour or more a day. They must be reset daily, or battery powered timers may be used. Where a sequential switcher is used to record from multiple sites on a single VCR, the switcher may be designed to turn on and off lights, reducing power requirements by illuminating only the site being recorded from.

8.0 DISCUSSION

The ability to measure the frequency of rare events through the use of time-lapse recording, and to non-intrusively observe nocturnal behaviours of animals represent significant advances in our efforts to understand the ecological organization of nearshore communities and the evolution of the species that are a part of them. We have used such a system to measure the intensity of the risk of fish predation from the point of view of benthic invertebrate prey (Collins

1989); to estimate the mean levels and spatial and temporal variance in the rate of exploitation of benthic invertebrates by fishes (Collins 1989); to determine whether benthic exploitation rates by fishes are higher in spatially complex sites than in open ones, and whether the contrast is affected by the presence/absence of piscivores; to determine whether smallmouth bass (Micropterus dolomieui) have the ability to defend their nests at night against nocturnal predators like brown bullhead (Ictalurus nebulosus), white sucker (Catostomus commersoni) and crayfish (Hinch and Collins in press); and to measure swimming speeds and diurnal activity patterns of fishes to improve our knowledge of the importance of activity in energy budgets (Hinch and Collins in press). Long-term time-lapse monitoring offers us much improved opportunities to describe the nature of the selective environment in the field, and to characterize how often the organisms we study are confronted with the conditions we simulate in the laboratory. The possibility of recording nighttime events is particularly exciting because almost all of our knowledge of the dark period to date comes from indirect measurements such as trap catches.

Time-lapse monitoring systems are also ideally suited for applied problems, such as determining the number, size, and species composition of fish moving through fishways or weirs, or for determining the responses of fishes to passive fishing gear.

The total cost of system components is coming down. A system for daytime-only recording at a single site would now cost about $5200 if self-assembled, $5600 off the shelf. Because of decreased camera costs, these values are almost $2000 lower than reported by Collins (1989). The total cost of a time-lapse field monitoring system will depend a great deal on the capabilities one needs and on the degree to which one wishes to assemble the system from modified components. Infrared lighting adds about $670 to the cost of a self-assembled system and $1600-$2400 to the cost of the most basic system off the shelf (including infrared filtration added by the user). The cost range for a lighted system ($5836-$8880) is still far below the $18,000

necessary for an unlighted image intensified camera and accessories. Use of a switcher, when continuous monitoring is not necessary, can reduce the price per site to $4200 for a 2-camera system and to only $3600 for a 3-camera system. Continuous monitoring of four sites using a quad unit would cost about $3900 per site. We hope the information in this paper will facilitate a better knowledge of the activities and environments of aquatic organisms in the field.

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